On-time constrained-envelope generator 106' operates in a manner analogous with the operation of off-time constrained-envelope generator 106. Threshold signal 120 and on-time signal stream 84 are combined in an on-time complex summing or combining circuit 122' to produce an on-time difference signal stream 124'. On-time difference signal stream 124' is passed to the input of an on-time discriminator 128' to produce an on-time error signal stream 130'. On-time error signal stream 130' is then passed to the input of an on-time pulse-spreading filter 134', which produces on-time constrained bandwidth error signal stream 108'. Like off-time pulse-spreading filter 134, on-time pulse-spreading filter 134', is substantially identical to first pulse-spreading filter 76.

Since on-time constrained-envelope error pulses (not shown) are derived from on-time pulses 80, the error-burst peak and zero values occur at integral baud times, i.e., at baud times t_1, t_2, t_3, etc., hence between datum-burst peak and zero values 102 and 104 of filtered signal stream 74.

Combining circuit 110 combines filtered signal stream 74, in the form of delayed signal stream 140, with both off-time and on-time constrained-bandwidth error signal stream 108 and 108' to reduce peak magnitude components of filtered signal stream 74.

A side effect of this methodology is that locus 72 at integral unit baud intervals 64 adds a signal-dependent, baud-limited noise factor to the positions of phase points 54 in constellation 46 (FIG. 3). This results in transmitter circuit 22 transmitting a "noise-influenced" phase-point constellation 46". In FIG. 7, noise-influenced constellation 46" is depicted illustrating constrained-envelope phase-point probabilities 144 of phase points 54 in accordance with a preferred embodiment of the present invention. The following discussion refers to FIGS. 2, 3, 5 and 7.

Phase-point probabilities 144 reside in noise-influenced constellation 46" exactly as phase points 54 reside in constellation 46, i.e., in the same configuration with centers at the same locations. The actual location of a given transmitted phase point 145 within a given phase-point probability 144 is a function of a plurality of variable conditions and, although somewhat correlated, except in certain specialized cases, cannot readily be predicted. In effect, for a given phase point 54, the resultant transmitted phase point 145 may be located anywhere within phase-point probability 144, i.e., within an indeterminate area having a center coincident with the location of the original phase point 54. The probability of transmitted phase point 145 being located at any specific position within that indeterminate area varies as an inverse function of the distance of that specific position from the location of the original phase point 54.

For any given phase point 54, the transmitted phase point 145 may be said to be proximate its idealized position within noise-influenced constellation 46". That is, a locus (not shown) of constrained-envelope signal stream 112 passes proximate the idealized positions of exemplary phase points t_0, t_1, t_2, etc., at the clocking instants in time.

The original phase points 54 of constellation 46, as produced by phase mapper 44, are on-time phase points 90 (circles) of expanded constellation 46'. It is these on-time phase points 90 that carry the intelligence of RF broadcast signal 26 as ultimately transmitted. Off-time phase points 92 (squares) are by-products of pulse-spreading filter 76, required to constrain spectral regrowth, and carry no intelligence. Phase-point probabilities 144 of noise-influenced constellation 46" represent the resultant areas of probable locations of transmitted phase points 145 as derived from on-time phase points 90. The centers of phase-point probabilities 144 occupy the same normalized locations within noise-influenced constellation 46" as do on-time phase points 90 within expanded constellation 46'.

The positional aberrations of transmitted phase points 145 relative to the corresponding on-time phase points 90 represent a degree of positional error. This positional error degrades the bit error rate and effects a detriment to transmission. The absence of off-time phase points 92 with a magnitude significantly greater than outer-ring magnitude 68 (FIG. 4) in constrained-envelope signal stream 112, however, allows an increase in power output for a given bandwidth and power amplifier that more than compensates for the position error of transmitted phase points 145. A net improvement in performance results.

Referring back to FIG. 2, the output of combining circuit 110, constrained-envelope signal stream 112, is passed to an input of a substantially linear amplifier 146. Substantially linear amplifier 146 produces RF broadcast signal 26, which is then broadcast via transmitter antenna 24. In the preferred embodiment, substantially linear amplifier 146 is made up of a digital linearizer 148, a digital-to-analog converter 150, and a radio-frequency (RF) amplifying circuit 152. Those skilled in the art will appreciate that substantially linear amplifier 146 may be realized in any of a plurality of different embodiments other than that described here, and that utilization of any of these different embodiment does not depart from the intent of the present invention nor the scope of the appended claims.

Within substantially linear amplifier 146, digital linearizer 148 alters constrained-envelope signal stream 144 into a pre-distorted digital signal stream 154. Pre-distorted digital signal stream 154 is made non-linear in just the right manner to compensate for non-linearities within digital-to-analog converter 150 and RF amplifying circuit 152, hence linearizing substantially linear amplifier 146.

Digital-to-analog converter 150 then converts pre-distorted digital signal stream 154 into an analog baseband signal 156. Analog baseband signal 156 is then amplified by RF amplifying circuit 152 into RF broadcast signal 26 and transmitted via transmitter antenna 24.

In summary, the present invention teaches a methodology and circuitry by which a transmitter circuit utilizing Nyquist-type filtration may produce a constrained envelope having a magnitude at or near the approximate unconstrained envelope magnitude of the desired constellation. This enables the transmitter output amplifier to be biased so that the maximum unconstrained envelope magnitude is at or near the top of the amplifier's linear region without incurring clipping of the constrained envelope transmissions. This in turn produces a more efficient output amplifier and effects an increase in the power output of a given output amplifier. Conversely, a lower power amplifier may be used to provide the same output power that was previously output. This effects a significant savings in output amplifier cost.

Although the preferred embodiments of the invention have been illustrated and described in detail, it will be readily apparent to those skilled in the art that various modifications may be made therein without departing from the spirit of the invention or from the scope of the appended claims.

What is claimed is:

1. A constrained-envelope digital communications transmitter circuit comprising:

a pulse-spreading filter configured to receive a quadrature phase-point signal stream of digitized quadrature phase

points and produce a filtered signal stream, said filtered signal stream exhibiting energy corresponding to each phase point spread throughout a plurality of unit baud intervals;

a constrained-envelope generator coupled to said pulse-spreading filter and configured to produce a constrained-bandwidth error signal stream;

a combining circuit coupled to said pulse-spreading filter and to said constrained-envelope generator, said combining circuit configured to combine said filtered signal stream and said constrained-bandwidth error signal stream to produce a constrained-envelope signal stream; and

a substantially linear amplifier having an input coupled to said combining circuit.

2. A digital communications transmitter circuit as claimed in claim 1 wherein said pulse-spreading filter is a Nyquist-type filter.

3. A digital communications transmitter circuit as claimed in claim 1 wherein said combining circuit is configured to combine said filtered signal stream and said constrained-bandwidth error signal stream to reduce a peak magnitude component of said filtered signal stream.

4. A digital communications transmitter circuit as claimed in claim 3 wherein said combining circuit is a complex summing circuit.

5. A digital communications transmitter circuit as claimed in claim 1 wherein:

said pulse-spreading filter is a first pulse-spreading filter;

said transmitter circuit additionally comprises a delay element coupled between said first pulse-spreading filter and said combining circuit; and

said constrained-envelope generator comprises a second pulse-spreading filter coupled to said combining circuit.

6. A digital communications transmitter circuit as claimed in claim 5 wherein:

said first pulse-spreading filter is configured so that each phase point is transformed into a Nyquist-type datum burst extending over a plurality of unit baud intervals, having a datum-burst peak value occurring in one of said plurality of unit baud intervals and datum-burst zero values occurring substantially at integral unit baud intervals away from said datum-burst peak value, so that said filtered signal stream in each unit baud interval substantially equals the sum of said Nyquist-type datum bursts from a plurality of phase points; and

said constrained-envelope generator is configured so that said second pulse-spreading filter receives error pulses, transforms each error pulse into a Nyquist-type error burst extending over a plurality of unit baud intervals, having an error-burst peak value occurring in one of said plurality of unit baud intervals and error-burst zero values occurring substantially at integral unit baud intervals away from said error-burst peak value, so that said constrained-bandwidth error signal stream in each unit baud interval substantially equals the sum of said Nyquist-type error bursts from a plurality of error pulses.

7. A digital communications transmitter circuit as claimed in claim 6 wherein said constrained-envelope generator is configured so that said Nyquist-type error bursts exhibit said error-burst peak values and said error-burst zero values at instances in time when said Nyquist-type datum bursts exhibit neither said datum-burst peak values nor said datum-burst zero values.

8. A digital communications transmitter circuit as claimed in claim 7 wherein said constrained-envelope generator is configured so that said error-burst peak values and said error-burst zero values occur approximately midway between said datum-burst peak values and said datum-burst zero values.

9. A digital communications transmitter circuit as claimed in claim 5 wherein said first and second pulse-spreading filters exhibit substantially equivalent transfer characteristics.

10. A digital communications transmitter circuit as claimed in claim 5 wherein:

said first pulse-spreading filter receives one quadrature phase point per unit baud interval and produces two complex samples of said filtered signal stream per unit baud interval;

said constrained-envelope generator evaluates one of said two complex samples of said filtered signal stream produced by said first pulse-spreading filter per unit baud interval; and

said second pulse-spreading filter receives one error pulse per unit baud interval and produces two complex samples of said constrained-envelope error-signal stream per unit baud interval.

11. A digital communications transmitter circuit as claimed in claim 1 wherein:

said filtered signal stream is a stream of complex digital values, with each of said complex digital values exhibiting a peak magnitude component; and

said constrained-envelope generator is configured to determine when ones of said peak magnitude components exceed a threshold value.

12. A digital communications transmitter circuit as claimed in claim 11 wherein:

said transmitter circuit additionally comprises a phase mapper coupled to said pulse-spreading filter and configured to select said digitized quadrature phase points from a phase-point constellation, said phase-point constellation having a maximum-magnitude phase point; and

said threshold value is a magnitude value approximately equal to a magnitude of said maximum-magnitude phase point.

13. A digital communications transmitter circuit as claimed in claim 1 additionally comprising an interleaver coupled to said phase mapper.

14. A digital communications transmitter circuit as claimed in claim 1 wherein:

said constrained-envelope generator is an off-time constrained-envelope generator;

said constrained-bandwidth error signal stream is an off-time constrained-bandwidth error signal stream;

said transmitter circuit additionally comprises an on-time constrained-envelope generator coupled to said pulse-spreading filter and configured to produce an on-time constrained-bandwidth error signal stream; and

said combining circuit is coupled to said pulse-spreading filter, to said off-time constrained-envelope generator, and to said on-time constrained-envelope generator, and said combining circuit is configured to combine said filtered signal stream, said off-time constrained-bandwidth error signal stream, and said on-time constrained-bandwidth error signal stream to produce said constrained-envelope signal stream.

15. A digital communications transmitter circuit as claimed in claim 1 wherein said substantially linear amplifier comprises;

a digital linearizer configured to pre-distort said constrained-envelope signal stream into a pre-distorted digital signal stream;

a digital-to-analog converter coupled to said digital linearizer and configured to produce an analog baseband signal from said pre-distorted digital signal stream; and

a radio-frequency amplifying circuit configured to generate a radio-frequency broadcast signal from said analog baseband signal.

16. In a digital communications system, a method for the transmission of a constrained-envelope communications signal, said transmission method comprising the steps of:

filtering a quadrature phase-point signal stream to produce a filtered signal stream, said filtering step spreading energy from each phase point in said filtered signal stream over a plurality of unit baud intervals;

generating a constrained-bandwidth error signal stream from said filtered signal stream and a threshold signal;

combining said filtered signal stream and said constrained-bandwidth error signal stream to produce a constrained-envelope signal stream;

linearly amplifying said constrained-envelope signal stream to produce said constrained-envelope communications signal; and

transmitting said constrained-envelope communications signal.

17. A transmission method as claimed in claim 16 wherein said combining step comprises the step of reducing a peak magnitude component of said filtered signal stream.

18. A transmission method as claimed in claim 16 wherein:

said generating step comprises the step of filtering an error signal stream having one error pulse per unit baud interval to produce said constrained-bandwidth error signal stream, said filtering step spreading energy from each error pulse in said error signal stream over a plurality of unit baud intervals;

said transmission method additionally comprises the step of delaying said filtered signal stream to produce a delayed signal stream; and

said combining step combines said delayed signal stream and said constrained-bandwidth error signal stream to produce said constrained-envelope signal stream.

19. A transmission method as claimed in claim 16 wherein:

said filtering step comprises the step of receiving one quadrature phase point per unit baud interval;

said filtering step additionally comprises the step of producing two complex samples of said filtered signal stream per unit baud interval;

said generating step comprises the step of evaluating one of said two complex samples of said filtered signal stream per unit baud interval to produce an error signal stream having one error pulse per unit baud interval; and

said generating step additionally comprises the step of filtering said error signal stream to produce said constrained-bandwidth error signal stream having two complex samples of said constrained-bandwidth error signal stream per unit baud interval.

20. A transmission method as claimed in claim 19 wherein said generating step additionally comprises the steps of:

providing said threshold signal; and

determining when ones of peak magnitude components of a stream of complex digital values of said filtered signal stream exceed a threshold value of said threshold signal.

21. A transmission method as claimed in claim 16 wherein:

said filtered signal stream includes two or more complex digital values per unit baud interval, said complex digital values in said filtered signal stream exhibiting local peak magnitudes; and

said generating step is configured so that said constrained-bandwidth error signal stream includes two or more complex values per unit baud interval; said complex values in said constrained-bandwidth error signal stream being responsive to said local peak magnitudes of said filtered signal stream so as to spread energy from selected ones of said local peak magnitudes over a plurality of unit baud intervals of said constrained-bandwidth error signal stream.

22. A transmission method as claimed in claim 16 wherein said transmitting step continuously transmits said constrained-envelope communications signal.

23. A constrained-envelope digital-communications transmitter circuit comprising:

a binary data source configured to provide a binary input signal stream;

a phase mapper coupled to said binary data source and configured to produce a quadrature phase-point signal stream, wherein said phase-point signal stream has a predetermined number of symbols per unit baud interval, said predetermined number of symbols defining a phase point in a phase-point constellation;

a Nyquist-type filter coupled to said phase mapper and configured to produce a filtered signal stream;

a constrained-envelope generator coupled to said Nyquist-type filter and configured to produce a constrained-bandwidth error signal stream;

a delay element coupled to said Nyquist-type filter and configured to produce a delayed signal stream synchronized with said constrained-bandwidth error signal stream;

a complex summing circuit coupled to said delay element and said constrained-envelope generator and configured to produce a constrained-envelope signal stream; and

a substantially linear amplifier coupled to said complex summing circuit and configured to produce a radio-frequency broadcast signal.

24. A digital-communications transmitter circuit as claimed in claim 23 wherein said Nyquist-type filter is a first Nyquist-type filter, said filtered signal stream includes a first filtered-signal data stream and a second filtered-signal data stream, and said complex summing circuit is a first complex summing circuit, wherein said transmitter circuit additionally comprises a quadrature threshold generator configured to-provide a threshold signal, said threshold signal having a threshold value, and wherein said constrained-envelope generator comprises:

a complex summing circuit coupled to said first Nyquist-type filter and said quadrature threshold generator and configured to produce a difference signal stream, wherein said difference signal stream is a stream of difference pulses having difference-pulse values of a first polarity and difference-pulse values of a second polarity;

a discriminator coupled to said complex summing circuit and configured to produce an error signal stream from said difference signal stream, wherein said error signal stream is a stream of error pulses substantially coinci-

dent with said difference pulses of said difference signal stream, and wherein, when ones of said difference pulses have said first-polarity difference-pulse values, said coincident error pulses have error-pulse values substantially equal to said first-polarity difference-pulse values, and when ones of said difference pulses have said second-polarity difference-pulse values, said coincident error pulses have error-pulse values substantially equal to zero; and

a second Nyquist-type filter coupled to said discriminator and configured to produce said constrained-bandwidth error signal stream.

25. A digital-communications transmitter circuit as claimed in claim 24 wherein said transmitter circuit additionally comprises:

a convolutional encoder coupled to said binary data source and configured to produce an encoded signal stream; and

an interleaver coupled to said convolutional encoder and configured to produce an interleaved signal stream by temporally decorrelating said encoded signal stream.

26. A digital-communications transmitter circuit as claimed in claim 24 wherein:

said filtered signal stream is a quadrature signal stream having a locus that passes proximate one of said phase points of said phase-point constellation at integral unit baud intervals;

said first filtered-signal data stream comprises on-time samples of said filtered signal stream, each of said on-time samples occurring substantially coincident ally with said passage of said filtered signal locus proximate one of said phase points of said phase-point constellation; and

said second filtered-signal data stream comprises off-time samples of said filtered signal stream wherein each of said off-time samples occurs between adjacent ones of said on-time samples.

27. A digital-communications transmitter circuit as claimed in claim 26 wherein each of said off-time samples occurs substantially midway between adjacent ones of said on-time samples.

28. A digital-communications transmitter circuit as claimed in claim 23 additionally comprising an interleaver coupled to said binary data source and configured to provide an interleaved signal stream.

29. A digital-communications transmitter circuit as claimed in claim 23 wherein said constellation is an amplitude and phase shift keying constellation.

* * * * *